Tonkin+Taylor

17 October 2025
Job No: 1098196.1000

Greater Wellington Regional Council
C/- RCP
100 Cuba St.
Te Aro
Wellington 6011

Attention: [redacted]

Dear [redacted]

Waterloo Station

Geotechnical Considerations for Station Foundations and Parameters for Existing Subway

1. Introduction

T+T provided geotechnical services for the concept-lite design stage of the Waterloo Station Redevelopment project[1]. As part of this work, it was identified that site investigations were required to inform key geotechnical risks for the development and the existing subway. Dunning Thornton Consultants (DTC) is the project structural engineer.

Site investigation was carried out in August 2025 comprising 1 borehole and 10 cone penetration tests (CPT) up to 10m bgl, and groundwater monitoring. Refer Figure A1 in Appendix A for a site investigation plan. The borehole and CPT logs, and groundwater monitoring data is presented in T+T's geotechnical factual report[2].

Considering the new site investigation information, this letter presents:

- An updated inferred ground and groundwater model.
- Conclusions of liquefaction assessment and its impact to the proposed development foundations and existing subway.
- Commentary on the suitability of the concept foundation option for the pedestrian bridge and station building, with associated risks and mitigation options, particularly the thickness of suitable founding layer.
- Geotechnical parameters under liquefied conditions for the existing subway to assist DTC's seismic assessment.

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[1] Tonkin & Taylor Ltd (7 August 2025) Letter to Greater Wellington Regional Council titled (Waterloo Station Redevelopment, Geotechnical Report – Concept-lite Design Stage". T+T Ref. 1098196.0000.
[2] Tonkin & Taylor Ltd (6 October 2025) Report for Greater Wellington Regional Council "Waterloo Station, Geotechnical Factual Report" T+T Ref. 1098196.1000 v1.

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This work has been carried out in accordance with our proposal dated 14 May 2025 (T+T Ref. 1098196.1000). This letter should be read in conjunction with the Concept-Lite Design Stage Geotechnical Report[3].

2. Updated Ground and Groundwater Conditions

The updated inferred soil profile is shown in cross section in Figures A2 and A3 in Appendix A.

The following key items were identified:

- Layer 2: Upper Taita Alluvium / Melling Peat comprises considerable thickness of soft compressible soils. The layer is thicker towards the north, north-east of the site.
- Layer 3: Lower Taita Alluvium is present. This is the stratum that contains the suitable founding layer for deep foundations. However, this layer is deeper, thinner and less competent for founding towards the north-east of the site.
- Groundwater is generally high. A groundwater level of 1.2m bgl has been adopted for liquefaction assessment.

3. Liquefaction Assessment

The triggering of liquefaction, for each soil layer identified as being susceptible to liquefaction, has been assessed in accordance with the method proposed by Idriss and Boulanger (2014)[4]. This method is based on empirical relationships with CPT 'q_c' and fines content. The conclusions are summarised in Table 3.1. Liquefaction triggering in a ULS(IL2) earthquake is shown on cross sections in Appendix A.

Site specific geotechnical data is not available below 10m bgl, therefore a qualitative assessment of liquefaction risk has been carried out for Layers 4 to 6 based on adjacent site's information and past experience of sites with similar ground conditions in the Lower Hutt area.

Table 3.1: Liquefaction potential

Layer	Geological Unit	Conclusion
1	Fill	Expected to be above groundwater, not expected to liquefy.
2	Upper Taita Alluvium / Melling Peat	Widespread liquefaction is possible at PGA > 0.2g, M7.7 earthquake shaking.
3	Lower Taita Alluvium	Localised pockets/layers of liquefaction of non to low plasticity silt and medium dense sand is possible at PGA > 0.25g, M7.7 earthquake shaking.
4	Petone Marine Deposits (including aquitard)	Localised pockets of liquefaction of non to low plasticity silt and medium dense sand is possible at PGA > 0.25g, M7.7 earthquake shaking.
5	Waiwhetu Gravel (aquifer)	This layer is dense and therefore liquefaction is not expected.
6	Bedrock	Not susceptible to liquefaction.

3 Tonkin & Taylor Ltd (7 August 2025) Letter to Greater Wellington Regional Council titled (Waterloo Station Redevelopment, Geotechnical Report – Concept-lite Design Stage". T+T Ref. 1098196.0000.
4 Boulanger, R.W and Idriss, I.M., 2014. CPT and SPT based liquefaction triggering procedures." Report No. UCD/CGM-14/01, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, CA, 134 pp.

4. Proposed Pedestrian Bridge and Station Building Foundations

The following comments are made in relation to screw piles founding in the Lower Taita Alluvium (Layer 3) as a foundation option for these structures:

- The Lower Taita Alluvium appears to be present across the site. The layer is thicker and more competent toward the south, south-west part of the site, i.e. Zone 1 on Figure A1. Within Zone 1, it is expected that sufficient founding thickness within Layer 3 exists.
- The widespread liquefaction identified within Layer 2 will result in cyclic displacements in the order of 160mm. It is expected that screw piles can be designed for the associated kinematic loads imposed on them. Lateral spread is not expected.
- In the north, north-east part of the site, i.e. Zone 2 on Figure A1, there appears to be insufficient founding thickness within Layer 3. Local ground improvement is expected to be required to increase the bearing layer thickness. The ground improvement could comprise local jet grouting and target specific thickness to improve.
- Some liquefaction may occur beneath the founding layer causing post-earthquake settlements. There is limited information beneath 10m depth due to constraints in depth of investigation in the Lower Hutt area (presence of aquifer). Accordingly, we assess this settlement based on information further away from this site. The structural design should consider a total settlement of 100mm and a differential settlement of 50mm over 5m.

The following opportunities are identified which can be considered in future design stages:

- At this stage, the pedestrian bridge and station building are located in Zone 2. Relocating these to Zone 1 would reduce the extent of ground improvement required (potentially eliminate). However, we note that this may not be possible from a station functionality perspective.
- Advanced analyses (using developing theories and methodologies and finite element modelling) may show that the pockets/layers of liquefaction within Layer 3 are less prevalent in Zone 2 than current assessment suggests. This opportunity may reduce the extent of ground improvement required.

5. Existing Subway

In accordance with guidance published on the MBIE website, ground shaking hazard to be considered in geotechnical seismic assessment of existing building is based on Module 1 (Version 0, 2016). Peak ground acceleration (PGA) for the ultimate limit state (ULS) for both IL2 and IL3 structures is set out below.

- ULS(IL2, Subsoil Class D) PGA = 0.35g.
- ULS(IL3, Subsoil Class D) PGA = 0.45g.

The subway is founded within Layer 2. Widespread liquefaction has been identified within this layer in a >0.2g, M7.7 earthquake (approx. 60% ULS(IL2) or 45% ULS(IL3) earthquake shaking). Geotechnical consequences to the subway include:

1. Liquefaction induced uplift pressures on the base of the structure.
2. Large seismic earth pressures on the subway walls due to liquefied soils and cyclic displacement.
3. Post liquefaction free field settlement resulting in differential settlement of structure.

Geotechnical parameters for these are provided in the following section.

5.1 Uplift pressure on base slab

Liquefaction induced uplift pressures will be imposed on the base of the subway. Uplift pressures in the order of 85 kPa is possible. This pressure would likely reduce with upward movement. If there are no restraint to the subway, hundreds of millimetres of total and differential displacement of the subway is possible.

5.2 Seismic earth pressures on walls

Liquefaction induced lateral ground movements (cyclic displacement) is possible in an earthquake where widespread liquefaction is triggered. Three scenarios should be considered to represent the ground behaviour during different stages of an earthquake. These scenarios are described in Table 5-1.

Table 5-1: Ground lateral behaviour during earthquake

Scenario	Description	Wall pressures
1	Start of earthquake. No liquefaction.	• Stiff wall earth pressures, see Figure B1 to B4 (1); plus • 100% structure inertia load distributed over wall area.
2	Liquefaction triggered. No lateral ground movement	• Liquefied active earth pressures, see Figure B1 to B4; plus • 100% structure inertia load distributed over wall area.
3	Liquefaction with cyclic (lateral) ground displacement.	• Liquefied passive earth pressures, see Figure B1 to B4. Pressures apply up to 160mm lateral displacement of the structure. Beyond 160mm, Scenario 2 earth pressures apply.

Note 1) Stiff wall earth pressures provided assume the structure is restrained by the station building. If not restrained, then only static earth and groundwater pressures apply (structure moves with the ground).

5.3 Post liquefaction free field settlement

The structural design should consider a total post-earthquake free field settlement of 200mm and a differential settlement of 150mm over 5m due to re-consolidation of liquefied soils.

5.4 Possible mitigation measures

We understand from DTC that the subway box will “hold together” under the above seismic earth pressures and liquefaction uplift pressures. However, the box will uplift due to insufficient self-weight.

If this performance is not acceptable, options to mitigate the effects could comprise the following or a combination of the following:

- Ground improvement e.g. jet grouting around and below the subway. Significant disruption to Cambridge Terrace can be expected.
- Sheet pile cut off or similar (e.g. secant bored pile wall) around subway. Significant disruption to Cambridge Terrace can be expected.
- Anchor subway down to mitigate uplift and structure strengthening but this option could reduce the usable space within subway.
- Drilling holes in the base slab to relieve uplift pressure and structure strengthening. This option will reduce the usable space within subway.

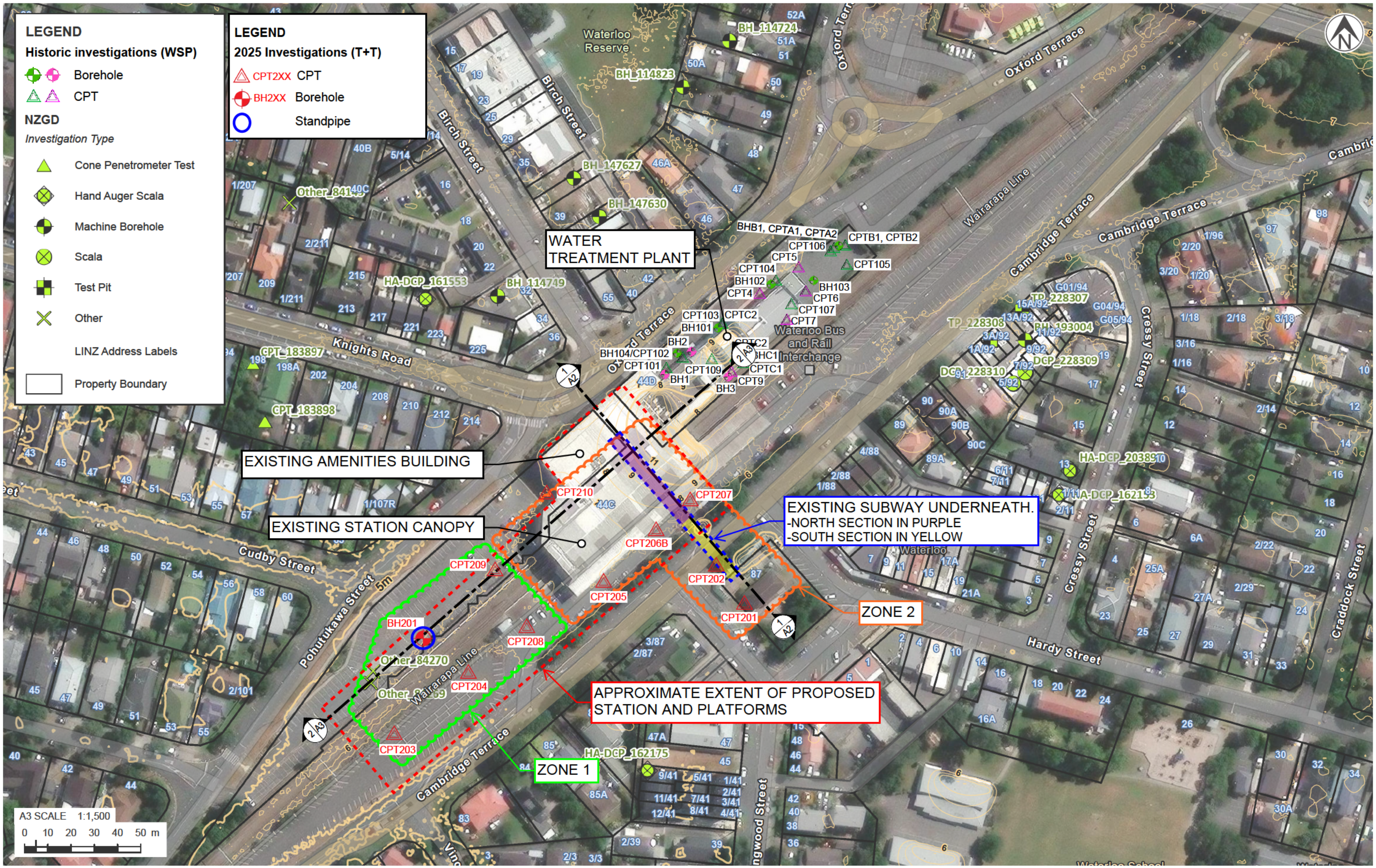
s7(2)(a) [redacted]

s7(2)(a) [redacted]

Appendix A Figures

- Figure A1 Site Investigation Plan
- Figure A2 Geotechnical Cross Section 1
- Figure A3 Geotechnical Cross Section 2

Tonkin + Taylor Map Viewer (NZ) Date: 25/02/2025 12:13 PM



![Tonkin+Taylor logo]

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NOTES:

CRS: NZGD 2000 New Zealand Transverse Mercator Credits: Tonkin & Taylor Group , Esri Community Maps Contributors, LINZ, Stats NZ, Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS, Earthstar Geographics, Maxar, LINZ, Stats NZ, Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS

LOCATION PLAN

PROJECT No.	1098196		
DESIGNED	BHR	FEB.25	
DRAWN	-WEB-	FEB.25	
CHECKED			
APPROVED		DATE	

CLIENT	GREATER WELLINGTON REGIONAL COUNCIL
PROJECT	WATERLOO STATION
TITLE	SITE INVESTIGATION PLAN

SCALE (A3) 1:1,500 FIG No. FIGURE A1. REV 0

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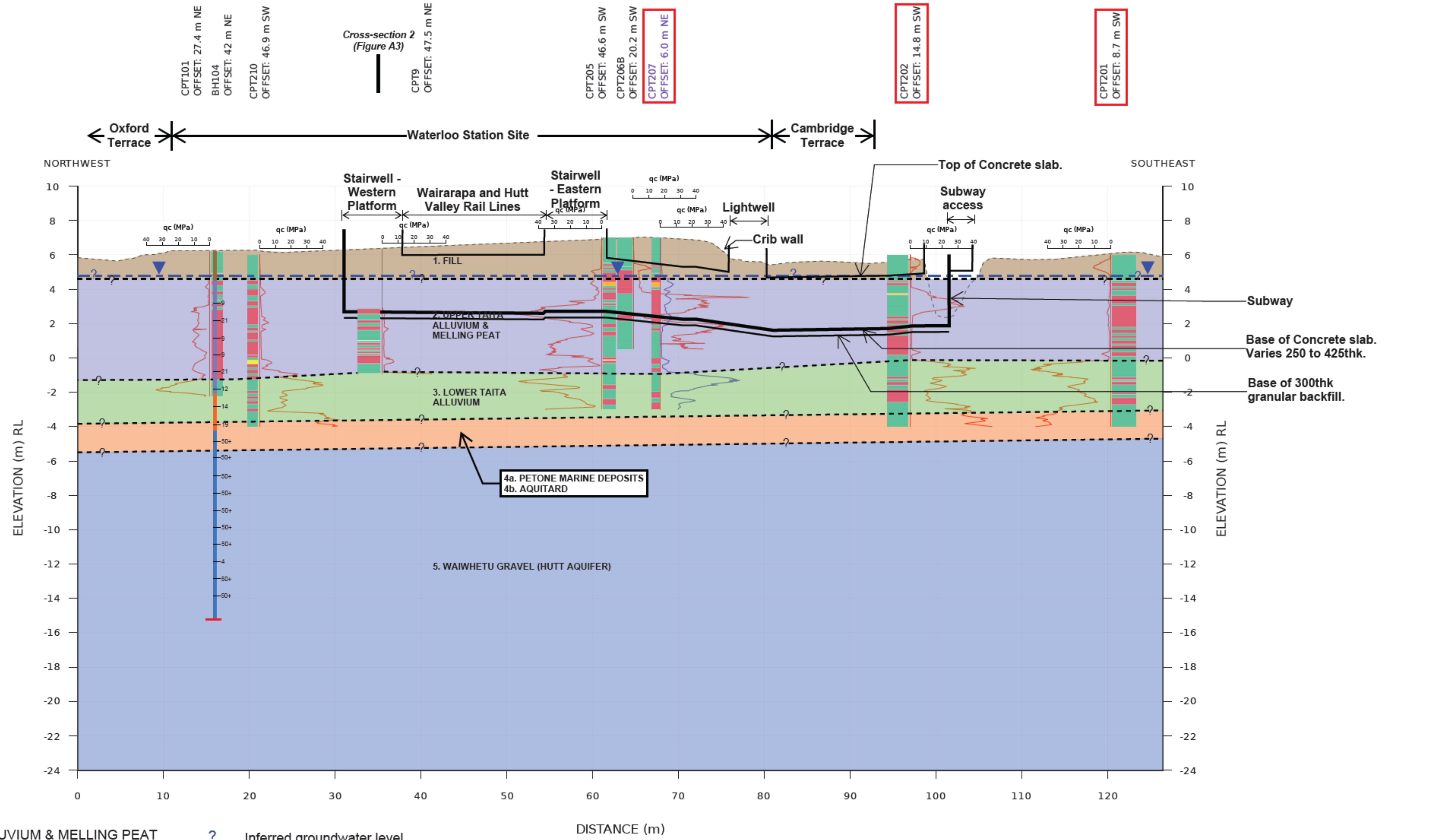

Legend

- 1. FILL
- 2. UPPER TAITA ALLUVIUM & MELLING PEAT (typically very loose SAND and very soft SILT; medium dense gravel/sand in places)
- 3. LOWER TAITA ALLUVIUM (typically dense SAND / GRAVEL)
- 4a. PETONE MARINE DEPOSITS (loose to very dense SAND / GRAVEL / SILT with shells)
- 4b. AQUITARD (predominantly overlapping discontinuous beds of clay / silt)
- 5. WAIWHETU GRAVEL (HUTT AQUIFER)

? Inferred groundwater level

? Inferred geological boundary

SECTION 1 / A1
SCALE: 1:500H (1:250V)

Cone Penetration Test (CPT)

qc (MPa) 0 10 20 30 40

TRACE OF UNCORRECTED CONE RESISTANCE (qc) WITH DEPTH

Liquefaction Triggering
- No triggering based on 15 percentile CRR curve
- Triggering based on 15 percentile CRR curve
- Triggering based on 50 percentile CRR curve
- Triggering based on 85 percentile CRR curve

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T+T Cross-Section Generator (CSG)
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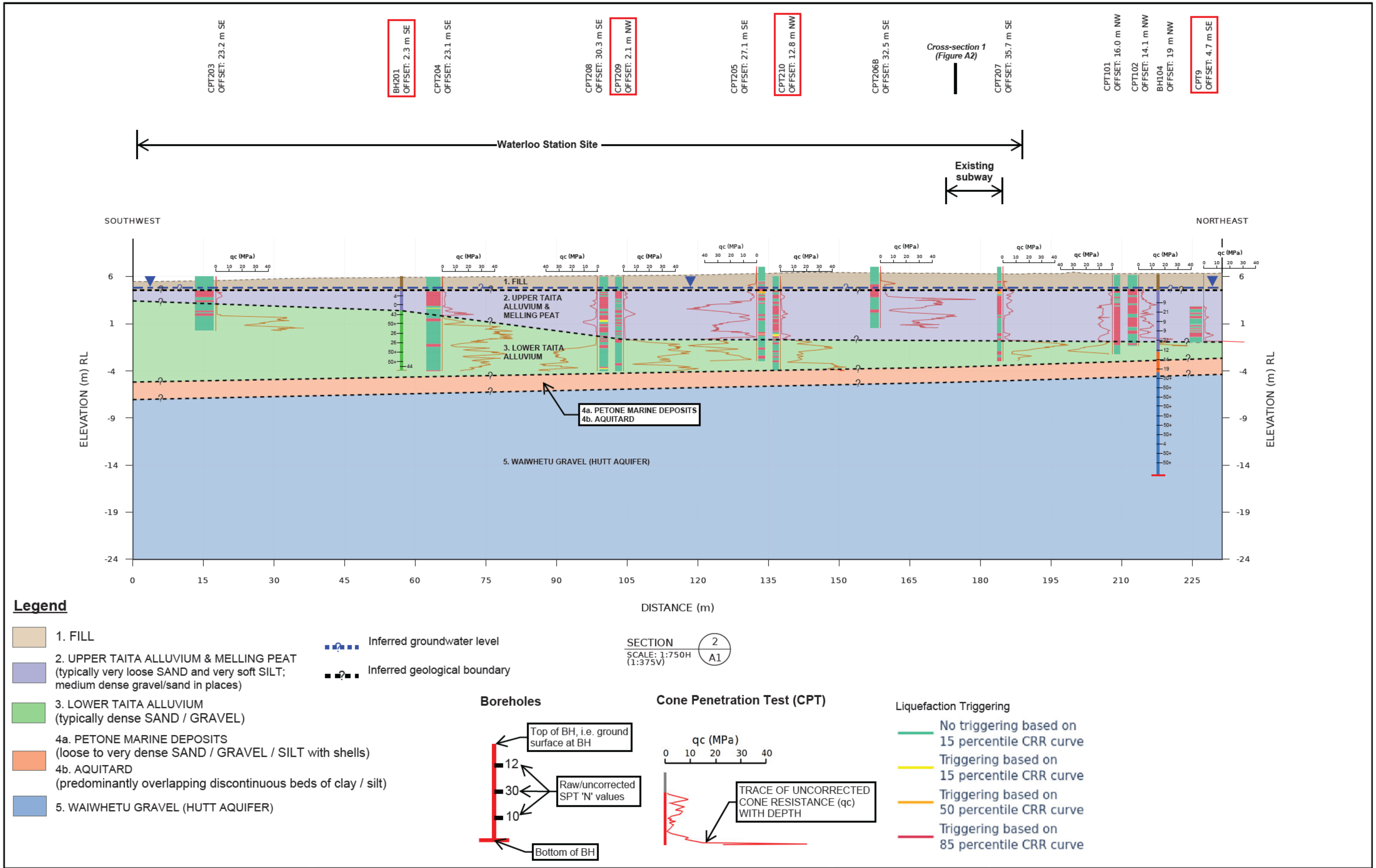
Groundline Source: Survey Name: hutt_city_2021 - Full DEM description not available
Warning: Investigations shown in red are not for external publication without the express permission of the client (Policy ID Type: T+T General).

PROJECT No.	1098196.1000	
DESIGNED	ANRO	Sep.25
DRAWN	ANRO	Sep.25
CHECKED	BHR	Sep.25
APPROVED		DATE

CLIENT GREATER WEALLINGTON REGIONAL COUNCIL
PROJECT WATERLOO STATION
TITLE GEOTECHNICAL CROSS SECTION 1
SCALE (A3) AS SHOWN   FIG No. A2   REV V1



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APPROVED	DATE	

CLIENT	GREATER WELLINGTON REGIONAL COUNCIL
PROJECT	WATERLOO STATION
TITLE	GEOTECHNICAL CROSS SECTION 2
SCALE (A3)	AS SHOWN
FIG No.	A3
REV	V1

Appendix B Wall Earth Pressures for Subway

Tonkin+Taylor	**Client:**	GWRC
	Project Name:	Waterloo Station
	Project No.:	1098196.1
	Structure:	Existing Subway

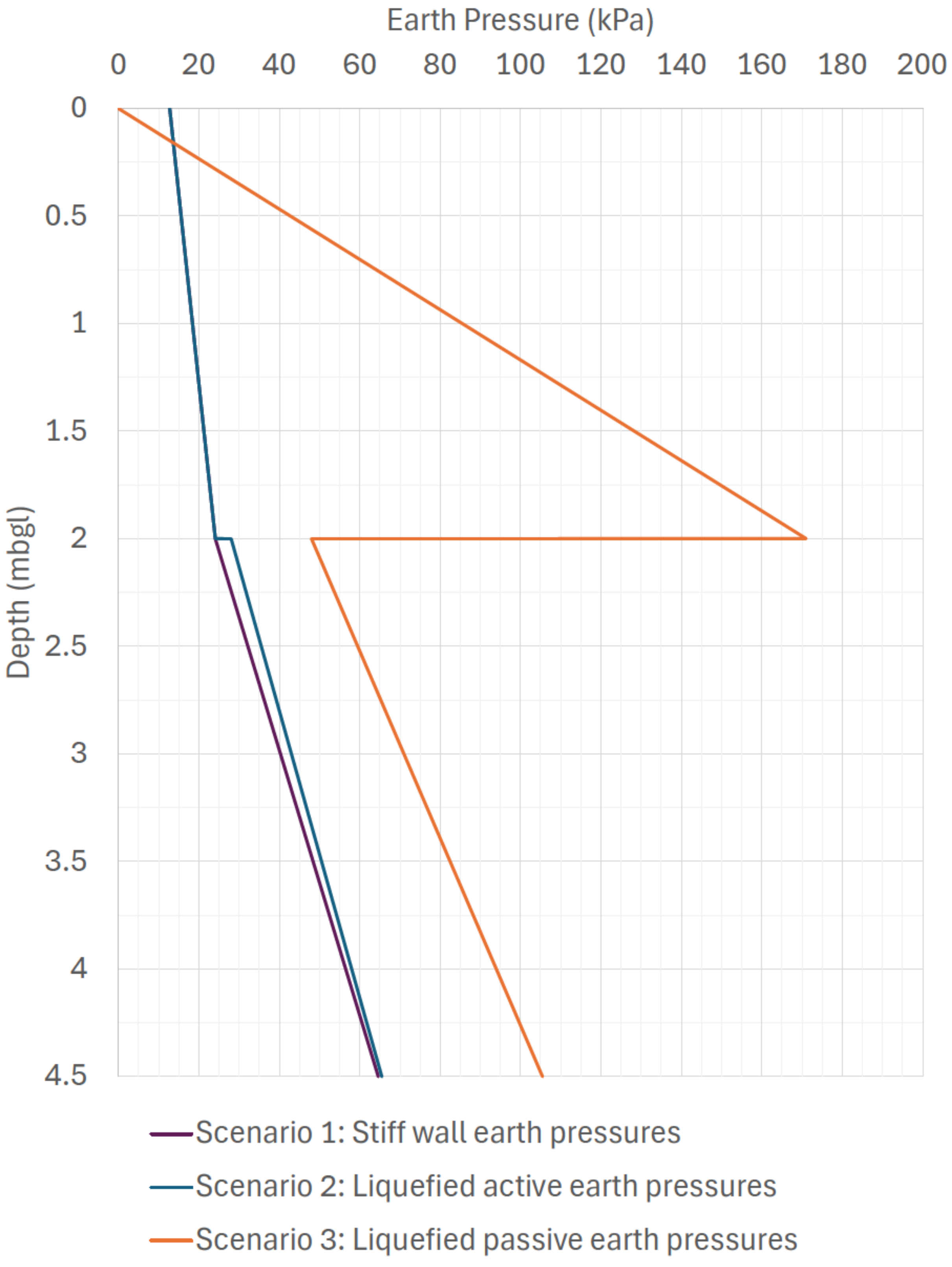

Figure B1	**Earth Pressures on Subway Walls - North Section (IL2)**
Calc/Chk: BHR/ELC	
Date: 16/09/2025	

Tonkin+Taylor	**Client:**	GWRC
	Project Name:	Waterloo Station
	Project No.:	1098196.1
	Structure:	Existing Subway

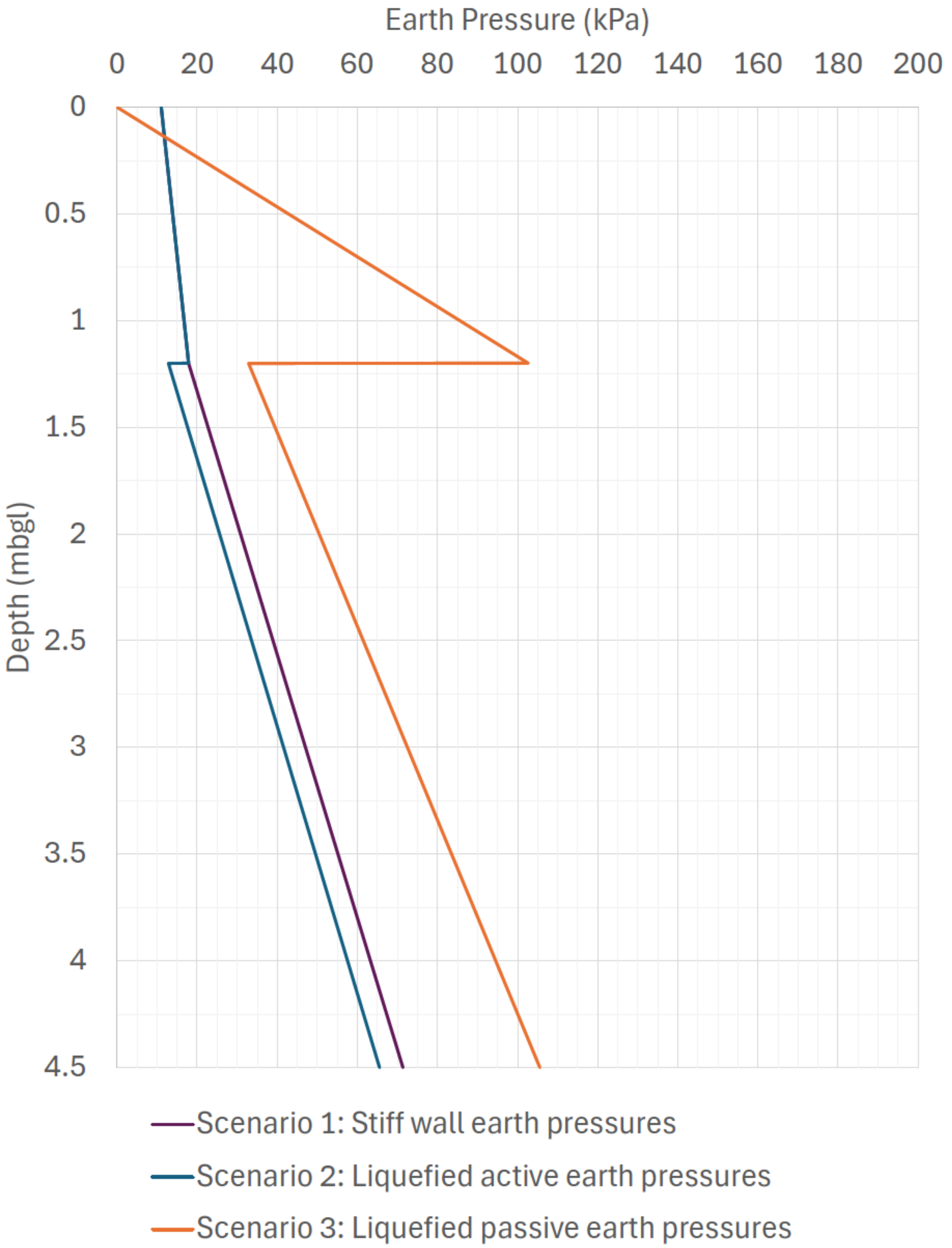

Figure B2	**Earth Pressures on Subway Walls - South Section (IL2)**
Calc/Chk: BHR/ELC	
Date: 16/09/2025	

Tonkin+Taylor

Client:	GWRC
Project Name:	Waterloo Station
Project No.:	1098196.1
Structure:	Existing Subway

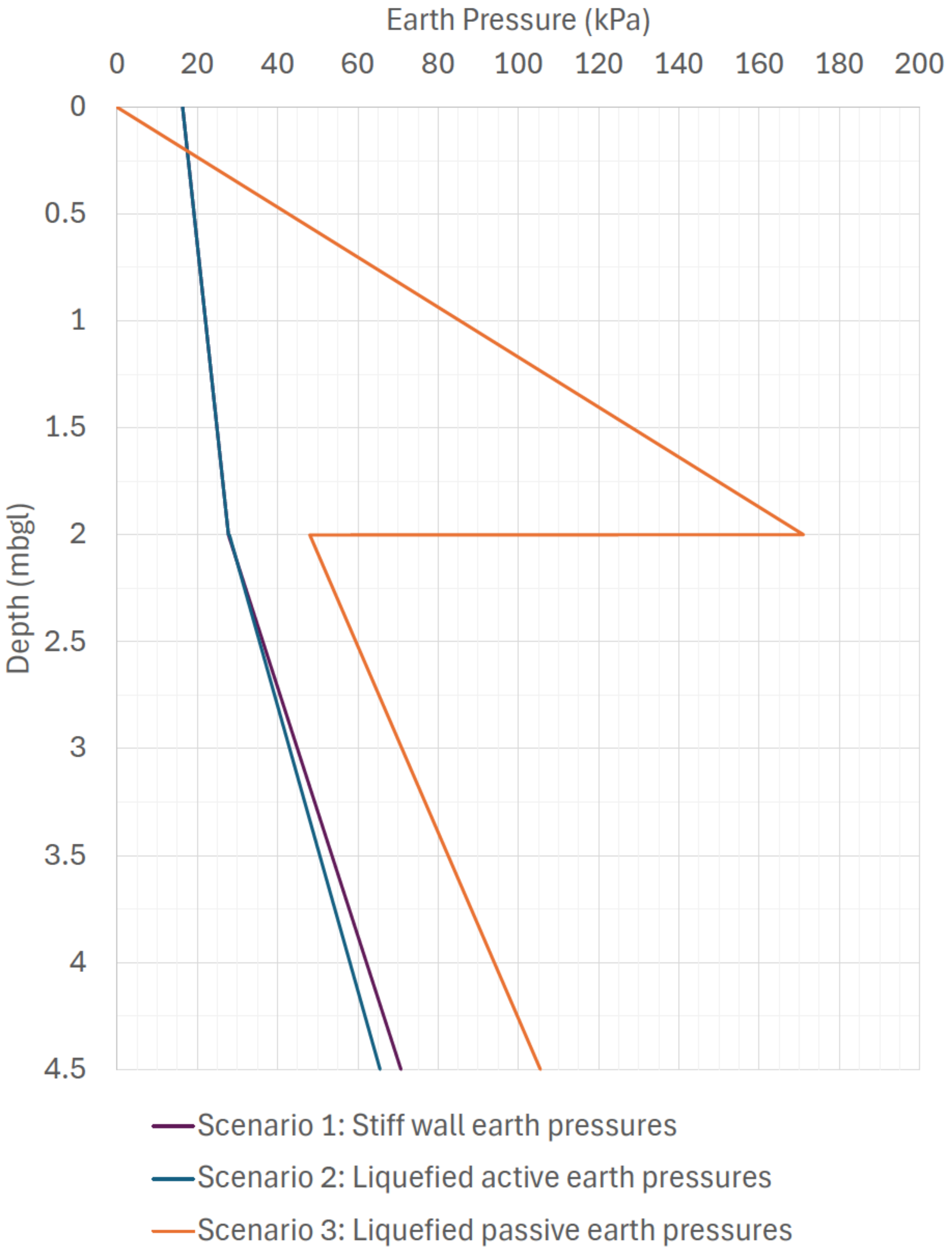

Figure B3
Calc/Chk: BHR/ELC
Date: 16/09/2025

Earth Pressures on Subway Walls - North Section (IL3)

Tonkin+Taylor		
	Client:	GWRC
	Project Name:	Waterloo Station
	Project No.:	1098196.1
	Structure:	Existing Subway

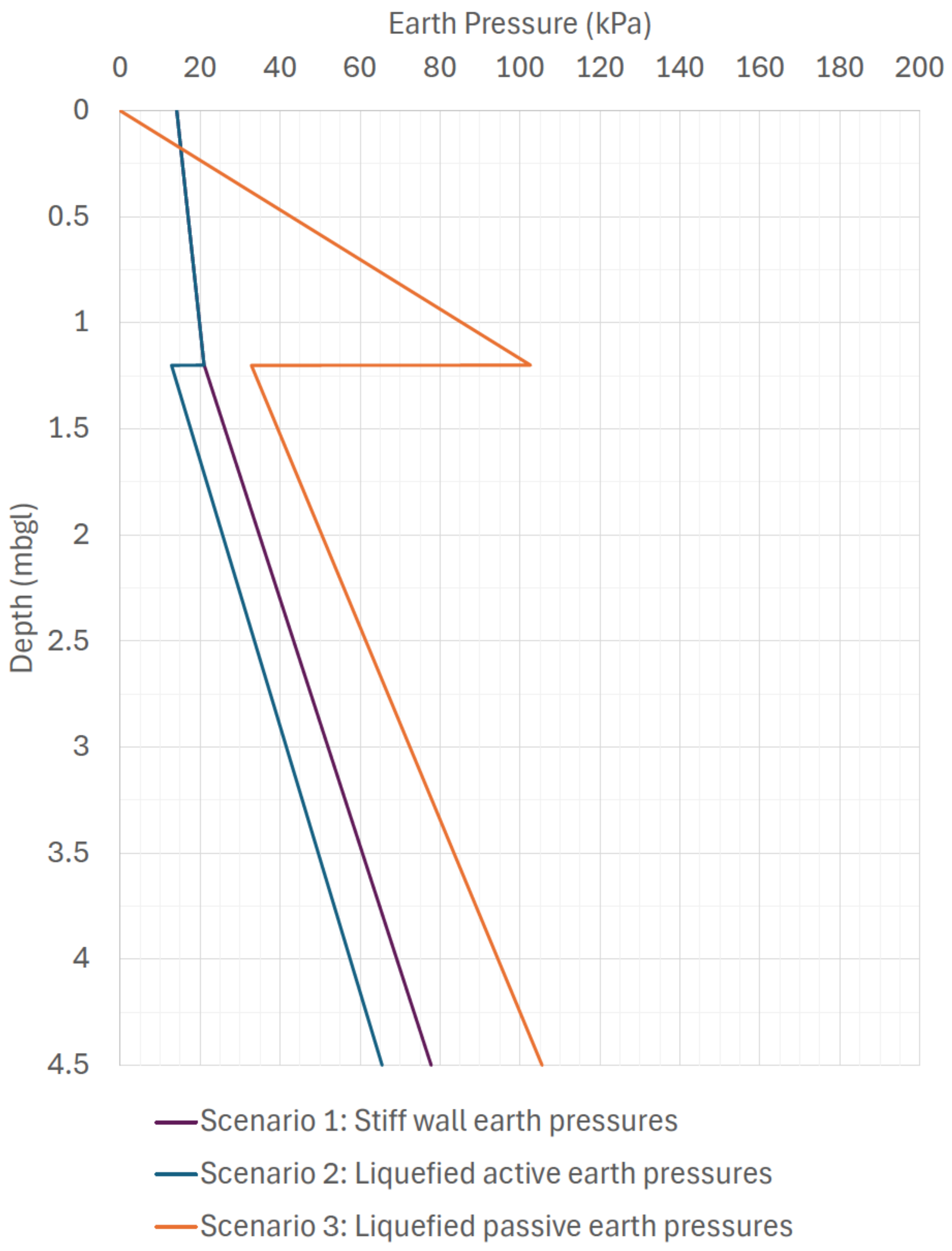

Figure B4 Calc/Chk: BHR/ELC Date: 16/09/2025	**Earth Pressures on Subway Walls - South Section (IL3)**